CLAIMS

What is claimed is:

1. A Machine for Production of Granular Silicon comprising:

a heating section located below a reacting section; where said heating section ~~can consist of~~ comprises one or more tubes heated by one or more heaters

a mechanism that pulses silicon granules back and forth between the heating and reacting sections ;

at least one separate injection ~~of~~ means for injecting silicon containing gases; ~~and~~

at least one separate injection means for injecting non silicon containing gases and

a heating means to heat the non silicon containing gases above ~~the~~ a reaction temperature; .

~~cooling each injection location of the silicon containing gases~~;

2. ~~a~~A machine of claim 1 where there are multiple stages; a 1st stage ~~each one consisting of~~ comprising a heater section, ~~and~~ a reaction section, a granule pulsing mechanism, a separate gas injection means for injecting silicon containing gases, a separate injection means for injecting non silicon containing gases and a heating means to heat the non silicon containing gases above ~~the~~ a reaction temperature and at least one additional stage comprising at least a heater section, a reaction section and a gas injection means. ~~where each reactor section has one or more injection nozzles for gases which promote additional reaction, in the silane reactor the gas to the reaction section would be silane, for the hydrohalosilane, e.g. trichlorosilane or tribromosilane reactor the gas to the~~

~~reactor section could be the hydrohalosilane alone, hydrogen alone or a combination of the two~~

3. a<u>A</u> machine of claim 1 ~~or 2 which~~ <u>further comprising the</u> recoverys <u>of</u> heat from <u>the</u> granules by direct contact with a high purity <u>gas, which has carbon and oxygen containing contaminants below 1 ppmwt and preferably below 10ppbwt and which can be</u> ~~non silicon depositing or reacting~~ gases: ~~such gases can~~ <u>selected from a 1st group consisting of</u> hydrogen, helium, argon, nitrogen <u>and mixtures thereof, or from a 2nd group consisting of</u> silicon tetrachloride and silicon tetrabromide but not mixtures of the ~~second~~ <u>2nd</u> group and hydrogen. ~~and must be low in carbon and oxygen containing contaminants, such as oxygen, water, carbon monoxide, carbon dioxide and methane, which contaminants must be below 1 ppmwt and preferably below 10ppbwt. Gases such as silicon trichlorosilane and silane are not usable because they decompose, hydrogen chloride, hydrogen bromide or mixtures of gases, which react such as a silicon tetrachloride, and hydrogen mixture are not usable because they can react with the granules~~

4. a<u>A machine of claim 1 further comprising</u> a heat exchanger in which the silicon containing gases are heated by hot liquid or condensing vapor maintained within a temperature range which cannot cause decomposition of the gases; which temperature range is typically between 200-400ºC but more particularly between 300-~~350~~ <u>360</u>°C.

5. <u>A machine of claim 1 further comprising</u> a sieving device, <u>operated either continuously or in batches,</u> by which <u>the</u> silicon granules are sieved using one or more sieves manufactured from non contaminating sieve material ~~and undersized granules returned to reactor; where the noncontaminating sieve material is~~ selected from ~~materials which contain silicon~~ <u>the group consisting of</u>

single crystal silicon, polycrystalline silicon, silicon oxide, silicon nitride, silicon oxynitride, ~~and~~ silicon carbide and mixtures thereof where the contaminants in the abradable surfaces ~~are low in contaminants, such as boron, phosphorus, aluminum, arsenic, iron, copper and other metals, such contaminants~~ will typically be below 1000 ppmwt and preferably below 100 ppmwt.

6. A machine of claim 1 further comprising ~~an optional~~ feedstock recovery section; where hydrogen is injected in the heating section, a silicon containing gas selected from a 1st group consisting of trichlorosilane dichlorosilane, tribromosilane, dibromosilane, triodosilane, diiodosilane and mixtures thereof is injected via the separate injection means for silicon containing gas in the reacting section and a silicon ~~quadra~~tetrahalide selected from a 2nd group consisting of ~~such as~~ silicon tetrachloride, ~~or~~ silicon tetrabromide and silicon tetraiodide is injected after the reactor section, mixed with the reactor effluent then quenched at an optimal temperature to recover ~~silicon hydrohalides~~ hydrohalosilanes selected from the aforesaid 1st group ~~such as trichlorosilane, and dichlorosilane,~~ residual silicon tetrahalides selected from the 2nd group and hydrogen.

7. A machine of claim 1 further comprising one or more cooled joints between external equipment and the reactor which transmit hot gases or solids and which are cooled using ~~localized~~, one or more, microchannels positioned to primarily cool the immediate area around the connection to the reactor and/or the seal area of the connection to the external equipment. ~~elastomeric O-ring to a temperature such that decomposition of the O-ring or increased permeability of the o-ring to oxygen, water and carbon dioxide does not cause significant contamination without excessive heat loss, such temperature is typically 25-300~~

~~C and preferably 50-150 C for o-rings made from high purity fluorocarbon o-rings such as Viton, Kalrez and Teflon~~

8. A machine of claim 1 ~~one or two where there is~~ further comprising external flow control of each said injection ~~point~~ means, ~~such flow control may be~~ either direct with flow control of each ~~nozzle~~ said means done independently, or indirect by means of a flow distribution device ~~such as a manifold~~ or a combination of the two where some ~~nozzles~~ of the said injection means are ganged in groups.

9. a~~A~~ machine of claim 1 ~~8~~where the instantaneous flow of gases into the reactor through one or more of the injection means is varied periodically ~~shape of the pulse~~ and/or the distribution of flow between said injection means ~~nozzles may be~~ is adjusted to control the generation of new particles without changing the total flow averaged over 1 minute.

10. ~~a preferred variation of claim 8~~A machine of claim 4 where the flow of silicon containing gas to ~~each nozzle~~ one or more of the separate injection means for silicon containing gas is controlled before the heat exchanger ~~heater/s~~ and an even more preferred option where multiple separate flows of the silicon containing gas are heated in the same ~~heater~~ heat exchanger.

11. ~~a preferred combination of the above claims for the use of silane as a feedstock~~, A machine of claim 2, where ~~there are; two or more stages~~; high purity hydrogen is used for the non silicon containing gas to the first stage ~~heating section~~ and silane is injected via the separate injection means for silicon containing gas in all the stages. ~~for the cooling of the granular silicon and for return of undersize granules to the reactor; the sieving device is made from high purity quartz tubes and polycrystalline silicon sieves, the feedstock recovery system is not used; cooled joints are used for all the inlets and outlets of the~~

~~reactor; the silane heat exchanger uses a condensing vapor maintained in the temperature range 340-360 C and each gas injection location is independently controlled.~~

12. ~~a preferred combination of the above claims for the use of trichlorosilane, and/or dichlorosilane as a feedstock~~, A machine of claim 2, where ~~there are; two or more stages~~; high purity hydrogen is injected in ~~used for the non-silicon containing gas to~~ the first and subsequent stages ~~heating section and to the second reacting section, for the cooling of the granular silicon and for return of undersize granules to the reactor; the sieving device is made from high purity quartz tubes and polycrystalline silicon sieves~~, a silicon containing gas selected from a 1st group consisting of trichlorosilane dichlorosilane, tribromosilane, dibromosilane, triodosilane, diiodosilane and mixtures thereof is injected via the separate injection means for silicon containing gas in the 1st stage and further comprising a final feedstock recovery system ~~is used and~~ where a silicon tetrahalide selected from a 2nd group consisting of silicon tetrachloride, silicon tetrabromide and silicon tetraiodide is injected, mixed with the reactor effluent then quenched at an optimal temperature to recover gases from the prior 1st group, residual silicon tetrahalides from the prior 2nd group and hydrogen ~~to cool the effluent from 1100 C to 900 C and hydrohalosilanes, for recycle ; cooled joints are used for all the inlets and outlets of the reactor; the chlorosilane the above said heat exchanger uses a condensing vapor maintained in the temperature range 340-360 C and each gas injection location is independently controlled~~

13. ~~a variation of claim 1,2,11 or 12~~ A machine of claim 1 where the heating~~er~~ section is of smaller diameter than the reacting~~er~~ section above it and connected by a tapered section, angle of said tapered section to be between 10

and 80 degrees from the vertical and preferably between 30-60 degrees from the vertical.

14. ~~a variation of claims 1,2,11,12 and 13~~ A machine of claim 1 where the heaters used in the heating sections are selected from the group consisting of ~~may be~~ resistance heaters, inductive RF heaters, microwave heaters, lamp heaters or lasers but are preferably resistance heaters.

15. ~~a further variation of claims 1,2,11,12 and 13~~ A machine of claim 6 where a ~~high efficiency~~ cyclone is used after the injection of the silicon tetrahalide to remove silicon dust ~~from the effluent gases~~ and to provide residence time for the mixing and reaction of the silicon tetrahalide with ~~from~~ the reactor effluent and the silicon dust to improve the ~~feedstock~~ recovery ~~system when this is used~~ of the said silicon hydrohalosilanes and tetrahalides.

16. ~~a yet further variation of claims 1,2,11,12 and 13~~ A machine of claim 1 where a silicon etching gas ~~or mixture of gases~~ may be injected through one or more ~~nozzles~~ of the injection means for the purpose of etching wall deposits from all or part of the reactor, ~~such~~where the gases ~~may be elemental halides such as~~ is selected from the group consisting of chlorine, ~~or~~ bromine, iodine, ~~hydrogen halides such as~~ hydrogen chloride, ~~or~~ hydrogen bromide, hydrogen iodide, ~~or combinations~~ a mixture of hydrogen and ~~silicon tetrahalides such as~~ silicon tetrachloride, a mixture of hydrogen and ~~or~~ silicon tetrabromide, a mixture of hydrogen and silicon tetraiodide and mixtures thereof.

17. ~~a additional improvement to the above claims~~ A machine of claim 1 where the reactor is supported upon a weigh cell, capable of both weighing the reactor and its contents and of measuring the intermittent force exerted by the pulsing ~~gas~~ granules and where the connections to and from the reactor are flexible enough to allow the slight deflection required by the weigh cell, said

deflection to be less than 1mm and preferably less than 0.5mm, and the thermal expansion of the reactor relative to the support structure, said thermal expansion to be less than 1" (25mm) and preferably less than 1/4" (6mm).

18. ~~a further variation on the above claims~~ A machine of claim 1 where all or a portion of the non silicon containing gases are heated to a temperature below the reaction temperature outside the heating section then heated to a temperature above the reaction~~or~~ temperature inside the heate~~r~~ing section prior to entry to the reactinge~~r~~ section.

19. ~~a yet further variation of claims 12 and 13~~ A machine of claim 2 where at least one of the second and subsequent stage heatinge~~r~~ sections ~~does~~ contains some residual silicon dust and/or silicon containing gases from the first stage reactinge~~r~~ section that ~~can~~ form a wall deposit.

20. ~~a variation of claim 5 where the sieving and return of undersize granules is done on a batch basis~~